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Long-term soil and shortleaf pine responses to site preparation ripping

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Abstract A shortleaf pine (*Pinus echinata* Mill.) ripping study was established by the Missouri Department of Conservation in March 1988 at the Logan Creek Conservation Area, USA. The objective of the study was to evaluate the effects of ripping on soil chemical and physical properties, on free-to-grow status, and on survival and growth of planted shortleaf pine seedlings. After 16 years, ripping increased exchangeable calcium; however, it had no long-term effects on soil particle size, organic carbon, pH, exchangeable potassium and exchangeable magnesium. Ripping increased the percentage of free-to-grow saplings by 3.8% after two growing seasons. Ripping improved survival by 4% during the 1st three growing seasons and by 7.1% at age 16. After two growing seasons, ripping improved crown spread by 13.6%, height by 14.2%, diameter by 14%, and volume by 41.2%. At age 16, ripping no longer had an effect on shortleaf pine height and had reduced diameter by 5.3% and volume by 11.0%. Our results suggest that ripping 1) had no effect on long-term physical properties or chemical properties of the soil, 2) had no effect on the number of free-to-grow seedlings, and 3) produced short-term benefits on survival and growth of planted shortleaf pine.

Keywords Soil physical properties · Soil chemical properties · Free-to-grow · Subsoiling · *Pinus echinata*

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Introduction

Shortleaf pine (*Pinus echinata* Mill.) is the only native pine species in Missouri. The range of shortleaf pine in Missouri has been reduced by over 90% (Essex and Spencer 1976) due to extensive logging, frequent wildfires and overgrazing (Brinkman and Smith 1968, Cunningham and Hauser 1989). Restoration of shortleaf pine in its former natural range is being accomplished through natural and/or artificial regeneration. Artificial regeneration of shortleaf pine, particularly in the Missouri Ozarks, presents numerous challenges where summer droughts are common, soils are rocky and contain hardpans, and hardwood vegetation competes with the planted seedlings. Ripping or subsoiling may be an alternative mechanical site preparation method for regenerating shortleaf pine on these harsh sites.

Ripping breaks up the hardpans or impervious subsoil layers, encouraging deeper root development and increased root growth area (Wittwer et al. 1986). On recently cleared sites, ripping may reduce woody competition during the first few years after planting and possibly eliminate the need for follow-up release treatments (Wittwer et al. 1986). Ripping can provide a catchment area for precipitation and could increase the soil volume available for storing soil water needed to carry tree saplings through summer droughts. In addition, site preparation ripping has the potential to affect both soil physical and soil chemical properties, which may in turn influence tree survival and growth.

Previous research has shown inconsistent changes in soil chemical and physical properties due to ripping. Bateman and Chanasyk (2001) and Wetter et al. (1987) found that ripping increased clay content in the Ap horizon. Wetter et al. (1987) found that ripping increased soil pH and soluble calcium in the Ap horizon. In contrast, Mathison et al. (2002) found no long-term differences between ripped and control treatments in soil texture, pH, bulk density, electrical conductivity or sodium adsorption ratio. Likewise, Johnson et al. (2002) found that ripping did not affect soil physical properties, total carbon, pH and extractable cations in Virginia Piedmont, USA. These mixed results underscore the need to understand effects of ripping on a range of soil types.

Ripping has been reported to improve survival and growth of planted shortleaf pine (Wittwer et al. 1986). In Georgia, ripping increased height growth by 17%, root-collar diameter by 15% and tree volume by 38% 5 years after planting (Berry 1979). In Arkansas, ripping reduced competition of weeds and other vegetation and improved planted pine survival by 20–25% (McClure 1984). In Missouri, ripping increased height growth by 54% after five growing seasons on the Mark Twain National Forest (McClure 1989).

The Missouri Department of Conservation (MDC) and Mark Twain National Forest began the trial use of ripping for shortleaf pine site preparation in the late 1980s. Initial results indicated that increased survival and growth might be expected using this practice (McClure 1989), but the long-term benefits of ripping have not been quantified. In 1987 a project was initiated to evaluate the efficacy of ripping as a site preparation method in Missouri Ozarks. The objectives were to determine the effects of ripping on 1) long-term soil chemical and physical properties, 2) free-to-grow status, and 3) survival and growth of planted shortleaf pine seedlings.

Materials and methods

Study site

The study site is located on Logan Creek Conservation Area in the Ozark Highlands of Reynolds County, Missouri, USA. The study site is classified by the ecological classification system for Missouri within the Current River Pine-Oak Woodland Dissected Plain Landtype Association (Nigh and Schroeder 2002). This landtype association is located along the periphery of the Current River Valley and is characterized by a moderately dissected upland plain associated with the Roubidoux Formation. Relief over large areas is generally less than 30.5 m. Historically, this area was dominated by pine and pine-oak woodland complexes. Sinkholes and other karst features are common within this landtype association.

The study location is on a ridge and upper west facing slope ranging from 0 to 10%. Soils on the ridge tops are Captina series which characteristically have a fragipan at a depth around 45–60 cm (Gott 1975). The original stand was dominated by black oak (*Quercus velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.) and white oak (*Q. alba* L.) and shortleaf pine and was destroyed by a tornado in 1985. A salvage harvest was done in the summer of 1987 prior to initiating this study.

Site preparation and planting

The site was bull-dozed on contour. The remaining stems and debris were windrowed on the contour. The site was ripped with a bulldozer and two toothed ripper during the winter of 1987 to break up the fragipan and to remove competing vegetation. Ripping was done when soil was dry to maximize fracturing. The ripper teeth were 2.14 m apart and the ripping depth was 60 cm. Genetically improved 1–0 shortleaf pine seedlings were planted on a spacing of 2.14×2.14 m and those in ripped sites were planted within the furrows in March 1988.

Study design

A randomized complete block design was used, with two treatments in a total of ten blocks of two plots each along the slope (Fig. 1). The treatments were: 1) ripped and non-ripped control. Each plot was four rows by ten seedlings with a buffer of two rows on each side and two seedlings on each end. Because of varying space between windrows and the need to avoid residual stumps, not all plots resulted in 40 measured seedlings per plot. The actual number varied from 37 to 66 measured seedlings per plot, with only two plots with less than 40.

Soil physical and chemical analyses

Five sampling locations were randomly picked within each treatment in April 2004, and at each location a soil pit, located within tree rows, was excavated with a backhoe. Depth to fragipan and thickness of fragipan were measured. Horizon depth was measured in each pit, and soil samples (> 300 g) were collected from each horizon for physical and chemical analyses. The Ap horizon had an average depth 10 cm, E horizon an average depth 20 cm and B horizon an average depth 167.5 cm.

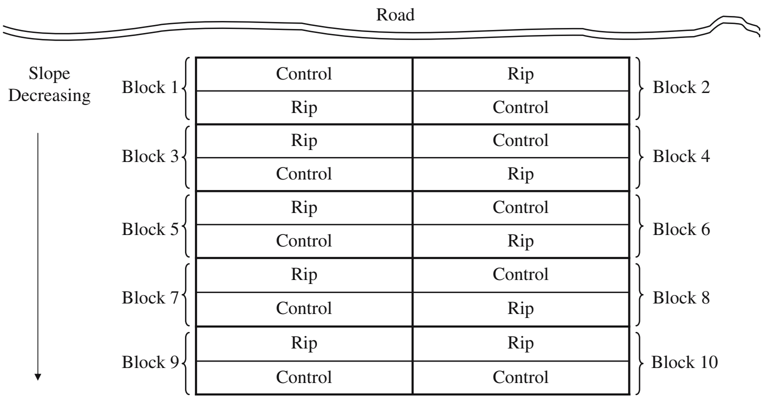

Fig. 1 Schematic diagram of the field layout. The ripping and control treatments were randomly assigned to each block

Physical and chemical analyses were conducted on air-dried and sieved (< 2 mm) soil. Soil physical and chemical analyses were carried out following standard methodology (Burt 2004). Soil exchangeable cations were extracted with a pH 7.0 ammonium acetate (NH_4OAc) solution and quantified using an atomic absorption spectrophotometer. Soil pH was determined in a 1:2 $CaCl_2$ solution to soil mixture. Soil physical parameters measured included texture and particle size analyses (Burt 2004).

Assessments

Free-to-grow was assessed December 1988, September 1989, and September 1990. Vegetation was considered overtopping the shortleaf pine seedlings if a leaf or branch of competing vegetation was located within an imaginary inverted cone of 45° each side of vertical above the terminal bud or vegetation covered the pine's terminal leader; otherwise the shortleaf pine seedlings were judged as free-to-grow. Total height (HT), crown spread, basal diameter (BD) at one inch above ground, and survival were measured December 1988, September 1989, and September 1990, except for basal diameter in 1990. The study was re-measured at age 16 in April 2004 for survival, height and diameter at breast height (dbh). Volume of stem at ages one and two were calculated using a volume index: HT $\times$ BD^2. Volume of stem at 16 years was derived using the following shortleaf pine volume equation developed by Gingrich (1962) for estimating merchantable volume with a minimum top diameter of 7.6 cm:

$$\text{Volume (m}^3\text{)} = -0.009062 + 0.00003255\ D^2H$$

where D is diameter at breast height in cm and H is height in meters.

Statistical analysis

Plot means were used for all analyses. Analyses were carried out for soil physical and chemical properties, survival, height, diameter, volume, crown spread and free-to-grow status for each age separately. Using the PROC GLM procedure in SAS (SAS Institute 1985), analysis of variance (ANOVA) tests were used to evaluate mean differences by treatments. Survival and free-to-grow percentages were analyzed using a Chi-square test.

Results and discussion

Soil physical and chemical properties

The depth to fragipan and thickness of fragipan was similar in the ripped and control treatments. Average depth to fragipan was 48 cm (range: 40–60) for control treatment and 52 cm (range: 38–69) for ripped treatment. Average fragipan thickness was 53 cm (range: 36–81) for control treatment and 41 cm (range: 23–51) for the ripped treatment. These results indicate that ripping at 46–61 cm would not have broken the fragipan. To break the fragipan at this site a ripper with teeth at least 100 cm long would have been required.

Particle size and organic carbon were not different between the control and the ripped treatments within the Ap, E, or B horizons (Table 1). This indicates that no physical effects were apparent from ripping, or if they had occurred, they had ameliorated over time. Also, the Ap horizon had been mixed during the windrowing operation and unlikely to show a ripping effect.

Exchangeable calcium was significantly higher in the ripped treatment than in the control treatment in the E-horizon (Table 1). Exchangeable potassium and magnesium, pH and cation exchange capacity were not significantly different between control and ripped treatments. Trace amounts of exchangeable sodium were detected in both treatments and were not reported. Ripping may have improved water movement through the soil profile allowing more leaching of calcium. Although the exchangeable cations in the rip treatment were generally higher than in the control treatment, the five samples taken from each treatment may not have been sufficient to detect significant differences because the ripping effects were variable. This indicates that little or no chemical effects were apparent from ripping, or if they had occurred, they had ameliorated over time. Our results are consistent with findings by Mathison et al. (2002) that there are no long-term soil physical effects due to ripping.

Short term effects on tree survival and growth

Seedlings in the ripped treatment had higher survival than seedlings in the control treatment at ages 1, 2 and 3 (Table 2). Survival at ages 1, 2 and 3 was above 90% for ripped and control treatments. Our results are consistent with other studies in the USA which showed that ripping improved survival of shortleaf pine (Berry 1979, McClure 1989).

At ages 1, 2, and 3, seedlings in the ripped treatment had greater diameter, volume and crown spread than those in the control treatment (Table 2). After the second growing season, pre-plant ripping had increased crown spread by 13.6%, height by 14.1%, basal diameter by 14.0% and volume by 41.2%. Although root systems were not assessed, a larger basal diameter is usually correlated with larger root systems. After three growing seasons total height in the ripped treatment was 147 cm and that in the control treatment was 131 cm, an increase of 12.3% (Table 2).

Table 1 Physical and chemical properties of ripped and control treatments in Missouri

	Particle size			Organic Carbon(%)	PH	Exchangeable (meq 100 g^{-1})		cations	CEC[+](meq 100 g^{-1})
	Sand (%)	Silt (%)	Clay (%)			Ca	K	Mg	
Ap –horizon (0 to 10 cm)									
Treatment									
Rip	21.2	67.1	11.7	1.90	4.8	1.6	0.14	1.02	10.2
Control	20.7	67.2	12.1	1.53	4.5	0.9	0.15	0.70	10.4
Pr > F	0.81	0.92	0.68	0.21	0.29	0.24	0.85	0.54	0.88
E-horizon (11 to 20 cm)									
Treatment									
Rip	19.3	66.6	14.1	0.68	4.4	0.78	0.14	0.94	8.8
Control	18.3	68.3	13.4	0.70	4.1	0.30	0.10	0.27	8.3
Pr > F	0.77	0.50	0.58	0.83	0.11	0.02	0.48	0.21	0.70
B-horizon (21 to 170 cm)									
Treatment									
Rip	20.0	42.8	37.2	0.25	3.9	0.48	0.18	1.68	14.7
Control	23.5	41.3	35.3	0.25	4.0	0.55	0.20	1.68	13.6
P-value	0.35	0.75	0.61	1.00	0.38	0.74	0.36	1.00	0.38

[+] CEC = Cation exchange capacity

Table 2 Effects of ripping on height, diameter, volume and crown spread at 1, 2, 3 and 16 years on shortleaf pine in Missouri

	Age (years)	Ripped	Control	Increase+ (%)	*P*-value
Survival (%)	1	96.8	92.9	4.2	0.006
Survival (%)	2	95.3	91.5	4.2	0.018
Survival (%)	3	94.9	91.3	3.9	0.026
Survival (%)	16	90.2	84.2	7.1	0.005
Height (cm)	1	25.1	22.7	10.6	0.065
Height (cm)	2	73.5	64.4	14.1	0.020
Height (cm)	3	146.9	130.8	12.3	0.010
Height (m)	16	10.7	10.6	1.3	0.360
Basal diameter (mm)	1	4.8	4.4	9.1	0.010
Basal diameter (mm)	2	13.0	11.4	14.0	0.019
Diameter (cm)	16	14.9	15.8	–5.3	0.005
Volume (cm^3)	1	6.8	5.0	36.0	0.021
Volume (cm^3)	2	148.7	105.3	41.2	0.018
Volume (m^3)	16	0.154	0.173	–11.0	0.016
Crown spread (cm)	1	14.3	11.4	25.4	0.004
Crown spread (cm)	2	44.2	38.8	13.6	0.028
Crown spread (cm)	3	75.4	67.6	11.7	0.007
Free-to-grow (%)	1	100	99.8	0	0.264
Free-to-grow (%)	2	97.3	93.7	3.8	0.024
Free-to-grow (%)	3	97.9	95.7	2.3	0.137

+ Increase due to ripping

The observed short-term improvement in survival and growth due to pre-plant ripping may have been the result of improved soil physical properties and/or improved soil-water extraction. It is not possible to relate the short-term results to soil properties because information on soil properties at the young ages is absent. In the Ouachita Mountains in Arkansas, USA, improved survival was attributed to a ripping creating a weed-free area with improved soil moisture and plantability (Mexal 1992).

Results during the sapling growth stage from our study are consistent with findings from other research of ripping effects on early survival and growth of shortleaf pine in the USA. In Missouri, a ripping study on the Salem Ranger District of the Mark Twain National Forest showed that shortleaf pine trees planted in a burned and ripped site were 53.8% taller than controls after 5 years (McClure 1989). Also, Berry (1979) reported that volume of shortleaf pine was improved by 38% at 5 years of age by ripping in a Piedmont site in Georgia. In Oklahoma, pre-plant ripping increased basal diameter of loblolly pine by 20% after two growing seasons (Wittwer et al. 1986). In contrast, early results from studies at 5 years or younger in Australia revealed that ripping had no significant effect on growth of slash pine (*Pinus elliottii* Engelm.) (Francis et al. 1984), and of *Eucalyptus*, *Melaleuce* and *Callitris* species (Knight et al. 1998). These differences probably reflect different soil physical properties or different requirements for the species involved.

Long-term effects on tree survival and growth

At age 16 survival in the control treatment dropped to 84.2% while that in ripped treatment averaged 90.2% (Table 2). The differences between ripping and control treatments were probably not operationally meaningful as survival of 84.2% after 16 growing seasons is well within acceptable limits for the region. The high survival rates for both treatments were a surprise given that the region experienced a dry summer the year seedlings were planted.

At 16 years of age trees in the ripped treatment had significantly lower diameter and volume than those in the control treatment, but there was no difference between height of trees in the ripped and the control treatments at 16 years of age (Table 2). While ripping increased diameter by 14.0% and volume by 41.2% after two growing seasons, the trees in the control treatment caught up and at 16 years the trees in the control treatment averaged 11.0% more volume and 5.3% greater diameter than trees in the ripped treatment.

Results of this study show that, while ripping at this site was beneficial at young ages, it was not at older ages. Thus, early assessments are not reliable for assessing benefits of ripping at older ages. The absence of long-term ripping benefits is likely to be due to the ripping depth not breaking the fragipan. It may also be due to the lack of long-term effects of ripping on soil physical and soil chemical properties. There is need to find the most appropriate ripping depth through the fragipan for different soil types. It is likely that competition confounded the diameter and volume results at 16 years. The higher survival of trees in the ripped treatment than in the control treatment could have resulted in higher competition in the ripped treatment. This could explain the lower diameter and volume growth in the ripped treatment than in the control treatment because diameter is sensitive to competition. However, the lack of long-term benefits of ripping is also shown by height, which is less affected by competition than diameter.

The success of ripping as a site preparation method depends on the long-term benefits of ripping out-weighing the costs. The costs of ripping should be offset by the savings in planting costs, improved survival (fewer seedlings needed), and more rapid early or sapling growth. Our study showed that pre-plant ripping benefited trees in the short-term, but not the long-term except for tree survival. Trees in control treatments had a slower start but they eventually out-performed the trees in the ripping treatment at 16 years at this site. This study has shown that conclusions regarding advantages of ripping based on a test evaluated at young ages do not reflect results at more mature ages.

Free-to-grow

The percentages of free-to-grow seedlings were higher ($P = 0.024$) in ripped treatment than in the control treatment after the second growing season (Table 2), but there was no difference in the percentage of free-to-grow seedlings between the ripped treatment and the control treatment after the first growing season and the third growing season.

The number of surviving seedlings in the free-to-grow status was greater than 93% in the ripped and control treatments across all the first three growing seasons. The high number of free-to-grow seedlings was consistent with high survival during the first three growing seasons. Although seedlings in the ripping treatment had a statistically significant higher number of free-to-grow seedlings in the second growing season, the increase was not of practical significance (< 4%) and was not observed in the long-term.

According to McClure (1984) the biggest advantage of ripping is that release herbicide will not be needed. In Missouri, herbicide release was normally applied during the 1980s at ages 3–5 to maintain a minimum of 1000 shortleaf pine seedlings per ha in a free-to-grow condition (McClure 1984). Our study shows that herbicide release is not required after 3 years on both the ripped and control treatments with more than 800 seedlings per acre in free-to grow status after three growing seasons in ripped and control treatments. Because the number of seedlings in free-to-grow status is high in both treatments, far fewer seedlings need to be planted to achieve 1000 free-to-grow seedlings.

The strength of this study was that it was assessed over a long period of time giving an opportunity to learn about the long-term effects of ripping. However, the study was limited by the fact that it was established at one site. Effects of ripping have been shown to differ among sites or geographic regions (Knight et al. 1998, Mathison et al. 2002).

In conclusion, depth of ripping in our study was not deep enough to fracture the fragipan and had no long-term effect on soil physical properties and few long-term effects on soil chemical properties. Initially, ripping resulted in short-term benefits for tree survival and growth; however, by mid-rotation, pre-plant ripping had resulted in decrease stem growth of planted shortleaf pine.

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